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Electric motor control

5 The invention relates to control of an electric motor
which can be switched between the motor mode and the
generator mode, is coupled or can be coupled to an
internal combustion engine and has an associated
battery, in particular in a hybrid drive with an
10 internal combustion engine and an electric motor which
can be switched between the generator mode and the
motor mode, as well as a battery, which is associated
with the electric motor and has a sensor system which
records its state of charge, in which case the internal
15 combustion engine and the electric motor are coupled
and/or can be coupled to the output drive of the hybrid
drive for drive purposes, and the electric motor can be
driven by the internal combustion engine and/or the
output drive during the generator mode.

20 Motor vehicles with hybrid drives have been in
development for a relatively long time. In general, in
the case of these drives, provision is made for the
electric motor which can be switched between the
25 generator mode and the motor mode to be continuously
connected, for drive purposes, to the drive train of
the vehicle and thus to the output drive from the
hybrid drive, which leads to the drive train. In
contrast, the internal combustion engine can be
30 switched by means of a clutch, that is to say when the
clutch is engaged the internal combustion engine is
connected to the drive train and to the electric motor
for drive purposes, and when the clutch is disengaged,
it is disconnected from the electric motor and from the
35 drive train. In principle, however, hybrid drives with
different configurations are also known, for example
those in which both the internal combustion engine and
the electric motor can be connected, via a separate

clutch in each case, to the output drive of the hybrid drive, and in a corresponding manner to the drive train of the vehicle.

5 One particular advantage of hybrid drives is that regenerative braking is possible, in which the electric motor which is connected to the drive train is operated as a generator and is driven via the drive train, so that the power supplied to the battery in the generator
10 mode is used for braking purposes, and is accordingly taken from the vehicle propulsion. In this way, the kinetic energy which is taken from the vehicle propulsion is converted to potential energy, that is to say in this case to increased battery charge, and is
15 not "wasted" as unusable heat as in the case of normal braking.

Furthermore, hybrid drives offer the vehicle the capability to be operated purely by the electric motor,
20 and thus without any exhaust gas emissions, in highly populated areas in which it can generally be expected that the vehicle speed will be comparatively low and that stopping maneuvers will occur very frequently.

25 Outside highly populated regions, the internal combustion engine can be used for propulsion to drive the vehicle. During these operating phases, the electric motor can be switched to the generator mode and can be driven by the internal combustion engine, so
30 that the battery which may possibly have previously been discharged can be recharged.

In this context, provision has until now been made for the generator power in the charging mode to be
35 controlled as a function of the state of charge of the battery, see, for example, the document "Analysing Hybrid Drive System Topologies", Karin Jonasson (2002), Lund University, ISBN 91-88934-23-3, page 74.

One object of the invention is now to improve the efficiency of a hybrid drive.

5 According to the invention, this object is achieved in that, during operating phases in which the internal combustion engine is operating and is coupled to the output drive, the electric motor operates

- predominantly in the generator mode only when the load on the internal combustion engine is low,
- 10 and/or
- predominantly in the motor mode when the load on the internal combustion engine is high.

The invention is based on the general idea of switching
15 the electric motor to the generator mode as far as possible only when the internal combustion engine is operating and when the additional load which this causes on the internal combustion engine leads to only a comparatively small amount of additional fuel
20 consumption. This is typically the case when the internal combustion engine is lightly loaded or is operating with high load reserves.

On the other hand, as far as possible, the electric
25 motor is used for the vehicle drive in addition to the internal combustion engine when the load reduction on the internal combustion engine which is achieved by operating the electric motor and the internal combustion engine in parallel leads to a comparatively
30 major reduction in the fuel consumption of the internal combustion engine. This is generally the case when high power is required for the respective operating phase of the vehicle, and the internal combustion engine is accordingly highly loaded.

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On the other hand, the invention takes account of the fact that the electric motor as well as the battery are virtually always more efficient than the internal combustion engine. On the other hand, the invention

makes use of the fact that the fuel consumption of the internal combustion engine when highly loaded rises more than in proportion to its load, so that on the one hand load increases on the internal combustion engine
5 when the total load is small lead only to a relatively minor increase in the fuel consumption of the internal combustion engine and, on the other hand, load reductions on the internal combustion engine when the load is high result in comparatively major savings in
10 the fuel consumption of the internal combustion engine.

The control principle according to the invention as described above can be carried out whenever the state of charge of the battery is neither above an upper
15 threshold nor is below a lower threshold and the battery can accordingly be used both for feeding the electric motor in the motor mode and for storage of the electrical energy which is produced by the electric motor in the generator mode, without any need to be
20 concerned about overcharging or undercharging of the battery.

On the basis of probability, conditions such as these occur at least during typical driving cycles so that
25 only in rare exceptional cases need the motor mode or generator mode of the electric motor or should the motor mode or generator mode of the electric motor be controlled exclusively as a function of the state of charge of the battery.

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According to one preferred embodiment of the invention, provision is made in the case of an internal combustion engine/electric motor combination or hybrid drives in which the electric motor is continuously positively
35 coupled to the output drive for no-load operation of the electric motor to be avoided, that is to say for the electric motor to be decoupled from the battery so that it can be operated neither in the motor mode nor in the generator mode. In fact, when the internal

combustion engine is operating, the electric motor is kept either in the generator mode or in the motor mode, and is switched between these modes, with the fuel consumption of the internal combustion engine being
5 operated.

This takes account of the fact that, when an electric motor is being operated on no-load, this causes more or less pronounced remagnetization losses, thus resulting
10 in unavoidable drag losses. This applies in particular to the permanent-magnet motors which are typically used in hybrid drives owing to their small physical volume. In this case, use is made of the fact that very high differential electric motor efficiencies can be made
15 use of in the transition from drag operation to the generator mode or motor mode.

Furthermore, the motor power and the generator power can preferably be controlled or regulated in order to
20 further optimize the fuel consumption.

One particularly preferred embodiment of the invention provides that data for changes which occur in the fuel consumption of the internal combustion engine which
25 occur in the event of load changes can be recorded as a function of the rotation speed of the internal combustion engine, and/or are stored, and the electric motor

- is operated as a generator when the quotient of
30 the load change and the consumption change exceeds a first threshold value

and/or

- is operated as a motor when the quotient of the load change and the consumption change of the
35 internal combustion engine is less than a second threshold value.

This makes use of the fact that internal combustion engines are nowadays normally provided with automatic

engine control which "knows" appropriate data or can in each case record such data in order to optimize the operation of the internal combustion engine in terms of low exhaust gas emissions, in order to achieve a
5 desired torque profile, and/or to achieve low fuel consumption. The data which is thus available in any case can then also be used to optimize the generator mode and/or motor mode of the electric motor.

10 Overall, this means that the respective differential efficiency, that is to say the quotient of load changes and consumption changes of the internal combustion engine, is taken into account, for the control of the operation of the electric motor.

15 In one expedient refinement of the invention, the generator power and/or the motor power of the electric motor can then be controlled analogously to the differential efficiency of the internal combustion
20 engine, by increasing the generator power as the differential efficiency rises in the generator mode, and by increasing the motor power as the differential efficiency decreases in the motor mode.

25 Apart from this, preferred features of the invention are described in the claims and in the following explanation of the drawing, on the basis of which particularly preferred embodiments of the invention will be described in more detail.

30 Protection is claimed, of course, not only for the expressly claimed or described feature combinations but also for, in principle, any sub-combinations of the described features.

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In the figures:

Figure 1 shows a schematic illustration of a hybrid drive,

Figure 2 shows a diagram illustrating when the electric motor or the internal combustion engine is preferably used to drive the vehicle, as a function of the state of charge SOC of the battery as well as the vehicle speed v , in a vehicle with a hybrid drive, and

Figure 3 shows a family of characteristics, which schematically illustrates the differential efficiency of the internal combustion engine as a function of the rotation speed n and of the mean combustion pressure p and/or the torque t of the internal combustion engine.

As shown in Figure 1, a typical hybrid drive 1 essentially comprises an internal combustion engine 2 and an electric motor 3, which can be switched between the motor mode and the generator mode, and whose power is generally considerably less than that of the internal combustion engine 2. An isolating clutch 4 is generally arranged between the internal combustion engine 2 and the electric motor 3.

The rotor shaft of the electric motor 3 forms the output drive 5 of the hybrid drive. This output drive 5 is connected, possibly via a transmission and/or clutch arrangement that is not illustrated, to a motor vehicle drive train that is not illustrated, when the hybrid drive 1 is arranged in the motor vehicle. When the clutch 4 is disengaged, the hybrid drive 1 can be operated purely by the electric motor, that is to say the output drive 5 is driven only by the electric motor 3, with a battery 6 which is associated with the electric motor 3 providing the electrical power.

When the clutch 4 is engaged, the output drive 5 can be driven by the internal combustion engine 3, in which

case the electric motor 3 can be operated as a generator, in order to charge the battery 6.

5 In principle, it is also possible for the electric motor 3 to be operated in parallel with the internal combustion engine 2 with the clutch 4 engaged, so that both the internal combustion engine 2 and the electric motor 3 drive the output drive 5.

10 Apart from this, the electric motor 3 can be operated as a generator whenever the aim is to brake the motor vehicle or the drive train which is coupled to the output drive 5. Thus, in this mode, the kinetic energy in the drive train and from the moving vehicle is
15 converted to electrical energy, and is stored in the battery 6.

As can be seen from the diagram in Figure 2, when the state of charge of the battery 6 is sufficient, a motor
20 vehicle with a hybrid drive is generally driven by the electric motor when the vehicle speed is low, that is to say exclusively via the electric motor 3. At higher vehicle speeds, a change is made to the internal combustion engine 2 to drive the vehicle.

25 If the state of charge of the battery falls below a threshold value of, for example, 50%, the change to the use of the internal combustion engine for driving the vehicle is made even at a low speed threshold of, for
30 example, 32 km/h. If, in contrast, the state of charge is above 50%, the change to the use of the internal combustion engine to drive the vehicle is generally made only at a speed threshold of, for example, 52 km/h.

35 If the state of charge of the battery falls below a value of, for example, 20%, the internal combustion engine 2 is used to drive the vehicle.

Switching between the use of the electric motor and the use of the internal combustion engine to drive the vehicle is generally influenced by further parameters, in particular by the position of an accelerator pedal or of some other device by means of which the desired power of the hybrid drive is controlled.

If, by way of example, the driver depresses the accelerator pedal to a major extent, this is an indication that he wishes to demand high power from the hybrid drive, for example for rapid acceleration of the vehicle. In typical hybrid drives, the electric motor 3 cannot provide such high power. In a situation such as this, a change is made to the use of the internal combustion engine to drive the vehicle even below the speed of travel thresholds illustrated in Figure 2, so that the high power desired by the driver is available. As soon as the driver relaxes the load on the accelerator pedal, that is to say when he is demanding only a comparatively low power from the hybrid drive, the system changes back to the electric motor drive for the vehicle, provided that the speed of travel is below the speed thresholds illustrated by way of example in Figure 2.

In order to keep the battery 6 within a desired state of charge range, the electric motor 3 must be operated in the generator mode during phases in which the internal combustion engine 2 is being operated.

The invention now provides for the differential efficiency of the internal combustion engine to be taken into account. This is the quotient between load changes on the internal combustion engine and changes associated with them in the fuel consumption of the internal combustion engine.

The invention makes use of the fact that, over a wide range of operating phases, increases in the load on the

internal combustion engine lead to only comparatively minor increases in the fuel consumption. The invention accordingly provides for the electric motor to be operated as a generator in these operating phases of the internal combustion engine, in which case, in one expedient refinement of the invention, it is also possible to provide for the generator power of the electric motor to be controlled as a function of the differential efficiency. In operating phases in which particularly minor increases in the fuel consumption of the internal combustion engine occur when the load on the internal combustion engine is increased, the electric motor is thus set to a particularly high generator power.

As is described further below, the abovementioned operating phases occur in particular when the load on the internal combustion engine is low, that is to say the electric motor is operated primarily as a generator when the internal combustion engine is having to provide only a reasonable amount of power for the respective driving state of the vehicle.

Furthermore, the invention makes it possible to make use of the fact that, in other operating phases of the internal combustion engine, in particular when the internal combustion engine is comparatively heavily loaded, load changes lead to relatively major changes in the fuel consumption. According to the invention, provision is in this case preferably made for the electric motor to be operated as a motor in parallel with the internal combustion engine, so that the internal combustion engine is less heavily loaded and the fuel consumption is considerably reduced because the electric motor provides a portion of the power which is required for the respective driving state.

In this case, it is expediently possible to provide for the motor power of the electric motor to be controlled

in inverse proportion to the differential efficiency of the internal combustion engine, that is to say the electric motor power rises when a load reduction on the internal combustion engine makes it possible to achieve
5 a comparatively major reduction in the fuel consumption of the internal combustion engine.

By way of example, Figure 3 now shows a schematic family of characteristics of the differential
10 efficiency of an internal combustion engine as a function of the rotation speed and the mean pressure in the combustion chambers, and the internal combustion engine torque, which is correlated with this.

15 The "contour lines" which are shown in the diagram indicate rotation speed/mean pressure combinations with the same differential efficiency, which is in each case indicated numerically. These figures are obtained by calculation, taking account of the fact that both the
20 load changes on the internal combustion engine and the changes in the fuel consumption associated with them physically represent power changes. This is because the power emitted from the internal combustion engine changes when its load changes. When the fuel
25 consumption changes, the quotient between the energy contained in the fuel and the time changes, that is to say the power consumption that is associated with the fuel consumption.

30 Expressed in simple terms, the diagram in Figure 3 shows that the differential efficiencies are comparatively high when the load and power of the internal combustion engine are low, and then decrease as the load or power of the internal combustion engine
35 increases.

This situation is equivalent to saying that the absolute efficiency of an internal combustion engine rises comparatively sharply in operating phases with a

low load or power as the load or power is increased, while the absolute efficiency of the internal combustion engine no longer rises or even falls, as the load or power is increased in operating phases in which
5 the load or power is high. Poor situations such as these occur whenever the differential efficiencies are less than the absolute efficiencies, which themselves at the moment are at best 30% to 35% in the case of an Otto-cycle internal combustion engine.

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The invention is not restricted to control of a hybrid drive in which the electric motor operates with the internal combustion engine shut down in specific operating phases. In fact, the invention can be used
15 whenever an internal combustion engine which is provided as the drive engine has an associated electric system which can be operated as an electric motor and generator. In the case of a motor vehicle, an electrical system such as this is used, for example, on
20 the one hand as a starter motor for starting the internal combustion engine, and on the other hand as a generator for charging a battery for the vehicle power supply system. During operation of the internal combustion engine, the electrical system can then be
25 controlled in completely the same manner as has been described above for the electric motor which can be switched between the motor mode and the generator mode in a hybrid system, during operation of the internal combustion engine.